NC PV DG Program
SEPA Presentation

renewable energy

our commitment to a sustainable future

Duke Energy

December 15, 2011

renewable energy

Agenda

- PV Industry Background
- PV Solar Rooftop Incident
- Root Cause(s)
- Wiring Diagrams
- Remedy
- Fire Safety Brochure
- Findings/Observations
- Recommendations

Duke Energy

renewable energy

PV Industry Background

- **Industry Trends**
  - Size of grid connected commercial PV Solar installations are increasing.
  - Larger systems have more direct current ("DC") equipment and wiring.
  - Unlike Europe, grounded designs are common in the U.S.
- **Changes in Design**
  - In 2005, large inverter manufactures changed their designs to incorporate a "lifted ground" to avoid nuisance trips. For example, a ground fault 5 amp fuse located in large central inverters is typical.
  - 2008 National Electric Code ("NEC") required a Ground Fault Protector ("GFP"). DC-GFP stop the current flow in the event of a short from the PV array.
- **DC Ground Faults**
  - Occur as a result of loose connections, damaged insulation, etc.
  - Megger test to find ground faults are done at the end of construction and periodic maintenance inspections, but rarely automatically in the US.

Duke Energy

renewable energy

PV Industry Background

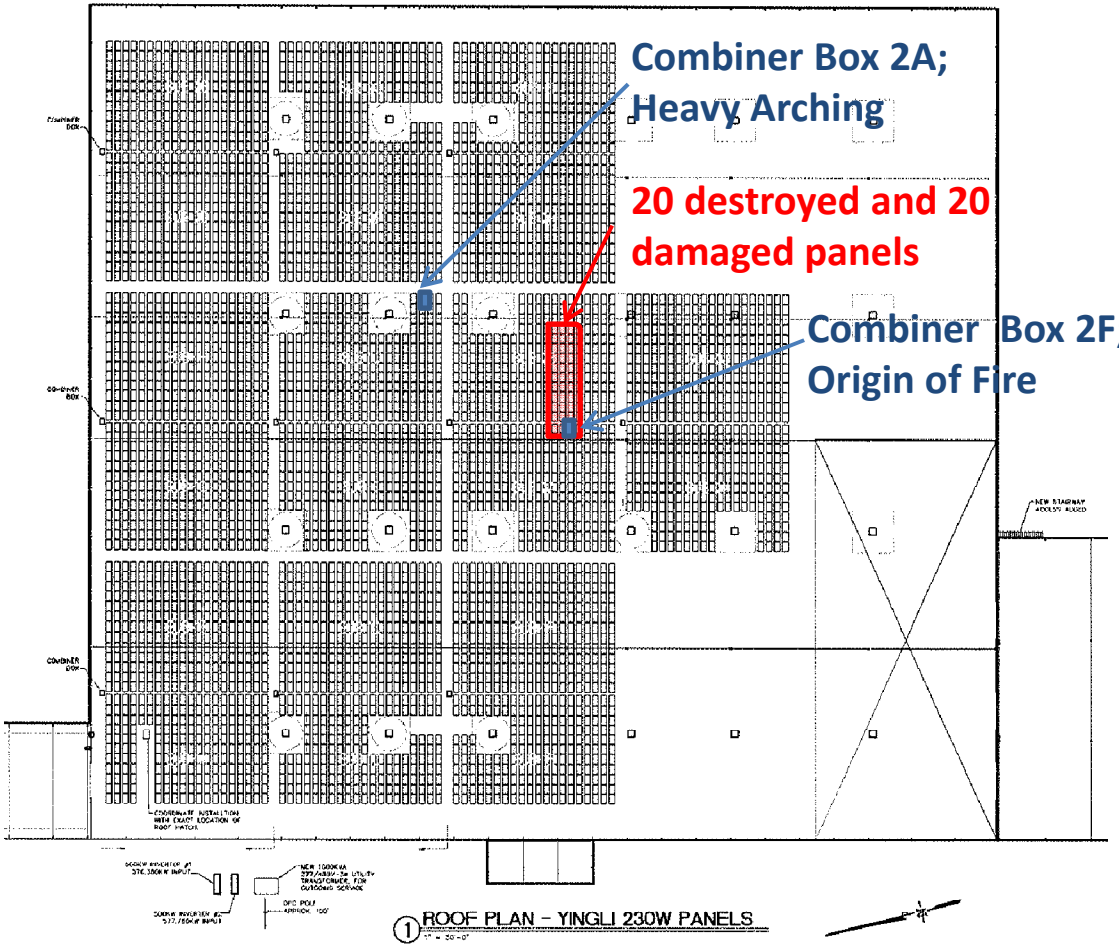
- **Undetected Ground Fault**
  - Forms a hazardous condition, but not normally a concern by itself because the current is dissipated in ground
  - If undetected, the system can not automatically shut down
  - Second ground fault escalates hazardous condition to a real concern
- **First Indication of Ground Fault Weakness**
  - Fire at 1 year old rooftop PV installation in Bakersfield, California on *April 5, 2009* – 383 kW
- **Confirmation of Ground Fault Weakness**
  - Second Fire at 1 year old rooftop PV installation at Duke's Mt. Holly site on *April 16, 2011* – 1208 kW
- **2014 NEC and UL** code committees are currently drafting language to remedy the industry wide weakness in *Ground Fault* protection

Duke Energy

renewable energy

PV Solar Rooftop Incident

Incident: PV Solar Fire
When: April 16, 2011
Where: Rooftop of Manufacturing Facility in Mount Holly, NC
What: Fire damaged or destroyed solar panels, combiner box 2F (fire), combiner box 2A (arching), and roofing.



5,252 230-Watt PV modules; Two inverters 500 kW inverters and one 135 kW inverter.

Duke Energy

Root Cause(s)

- **PV System Protection Design:** A low level ground fault (below 5 amps) is not detected with the GFP located in the inverter….aka the " Blind Spot"

- **Undetected grounded feeder conductor (2F) fault:** A string feeder (2F) ground fault occurred at an unknown time. Only a portion of the string operating current was directed toward the inverter through the ground. It was at a level insufficient (less than 5 amps) to be detected . As a result , the inverter did not trip.

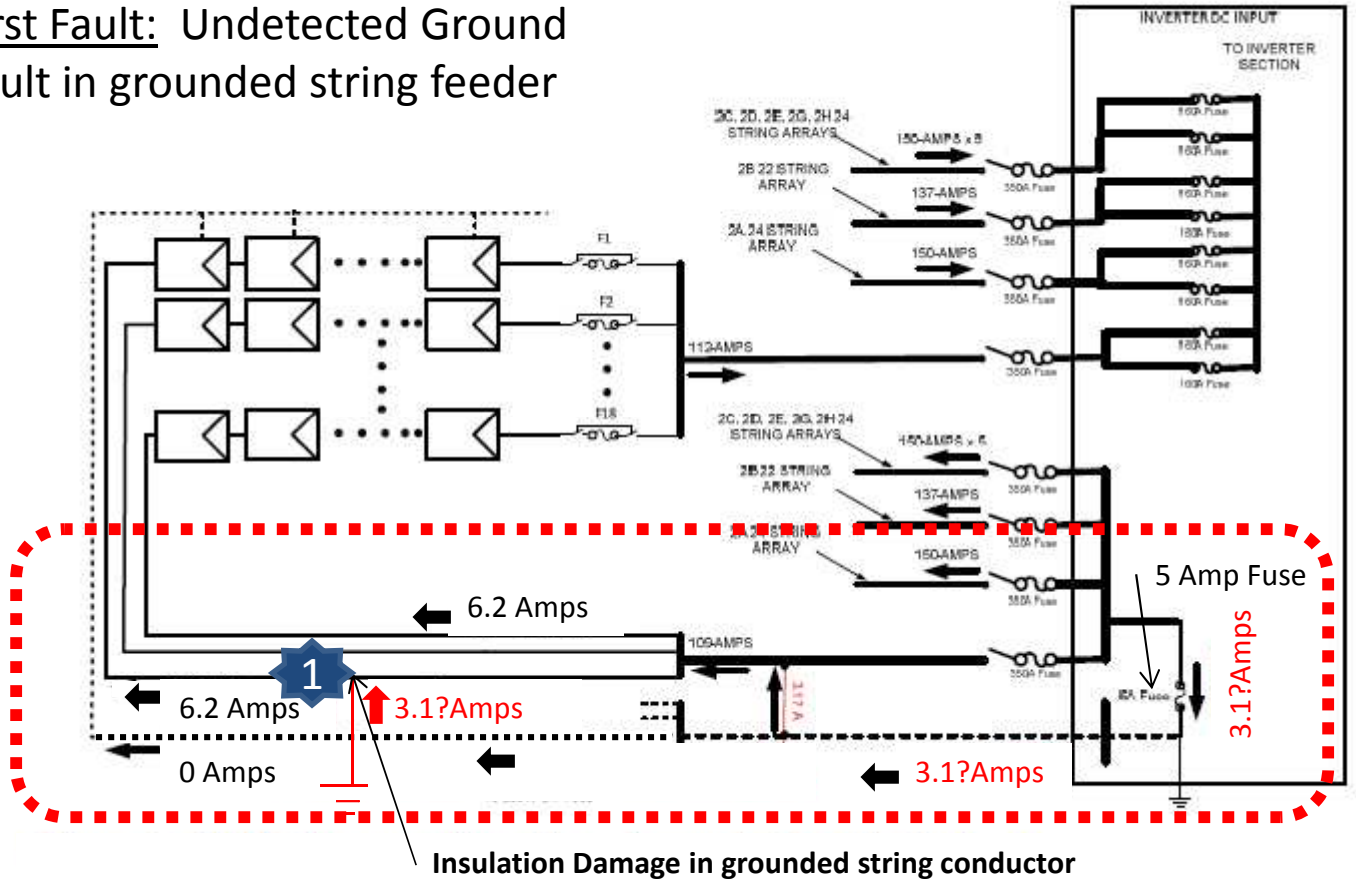
- **Second ungrounded string conductor (2A) fault:** A second ground fault on an ungrounded conductor (2A) occurred in a feeder that was connected to the same inverter. Arcing marks were identified where this feeder connected to the combiner box. The current in the ground from the second fault was large enough to trip the GFP. This current flow then went back trough the ground fault connection made by the first ground fault. This current exceeded that rating of the string feeder and associated equipment. This caused these component to be heated to the point of combustions.

Contributing Factors: Increased solar irradiance after storm, strong winds, some poor installation practices, thermal expansion, certain industry practices

renewable energy

Wiring Diagram

First Fault: Undetected Ground Fault in grounded string feeder

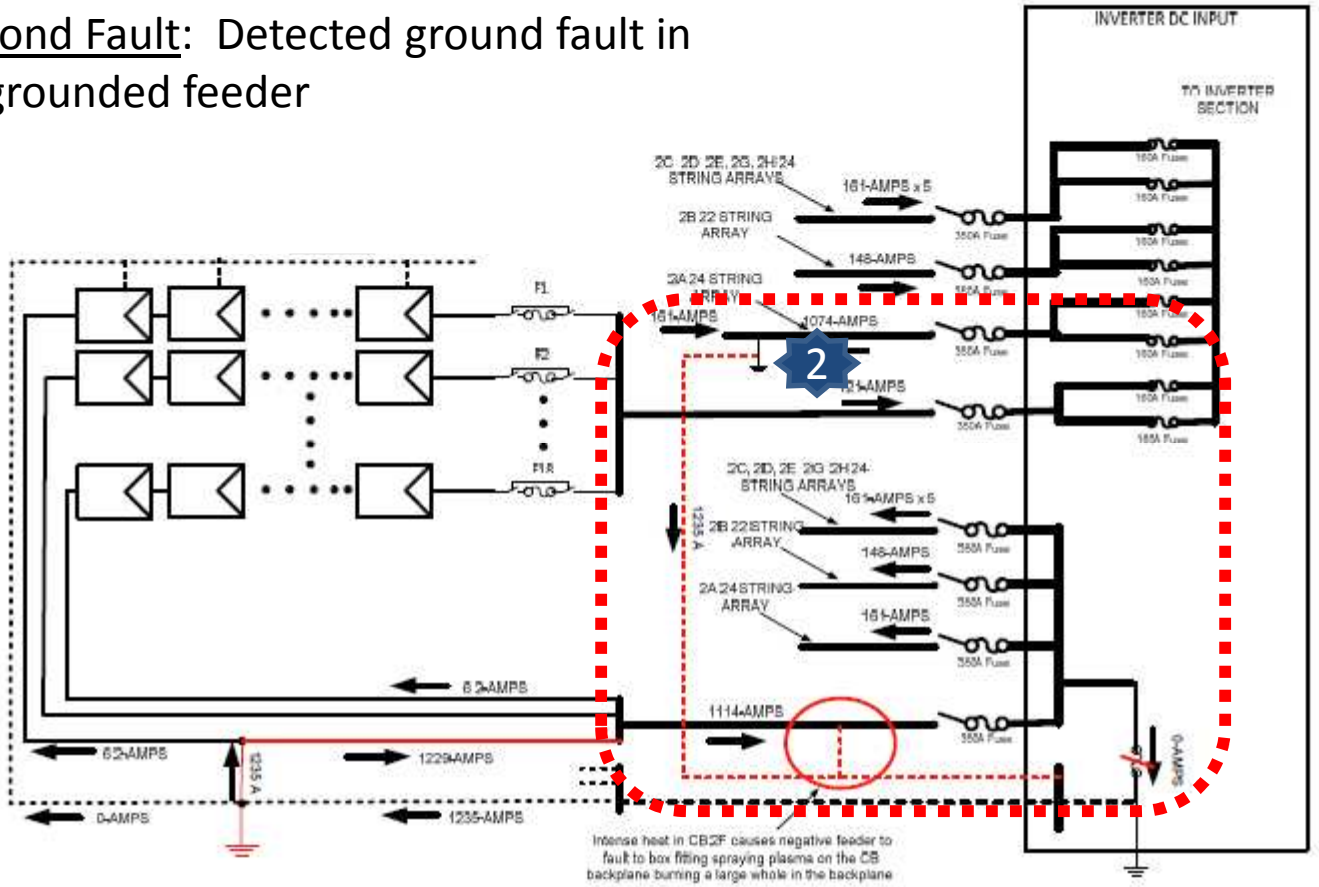


A Ground fault in ungrounded string feeder (normally operating between 6 to 8 amps) can be too low to be detected by the GFP in the inverter when current is split between the feeder and ground (3 to 4 amps).

Duke Energy

Wiring Diagram

Second Fault: Detected ground fault in ungrounded feeder

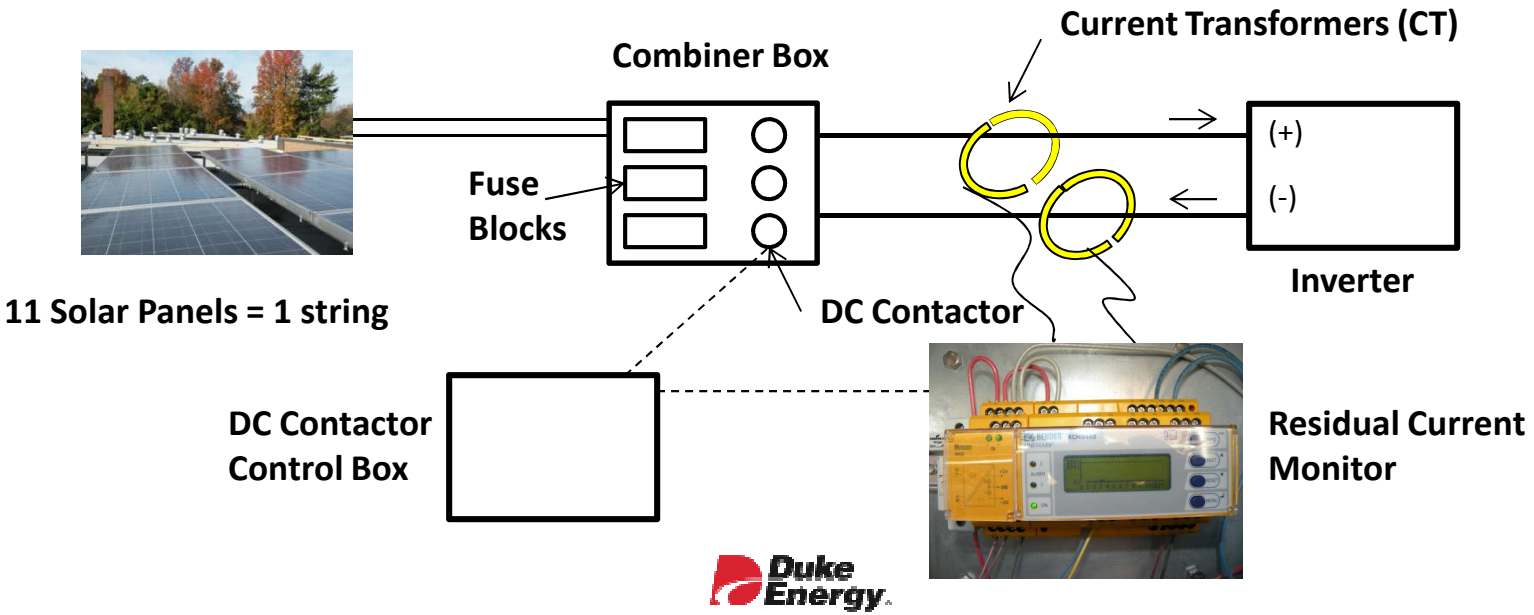


If second fault occurs in an grounded feeder, all current flowing to the inverters (1235 amps) from all of the combiner boxes can be re-routed to the ground and string conductors when GFP trips.

Duke Energy

Remedy

- **DC Residual Current Monitor (Ground Fault Detector)**
  - ❑ Measures imbalance of current flow in the positive and negative (grounded) feeders from inverter to each combiner box.
  - ❑ Detects all ground faults in ungrounded conductor but not some lower lever (approx. 0.2 amps grounded faults) in grounded conductor during operation
  - ❑ Equipment can detect some ground type Arc Faults
  - ❑ A 60 milliamp alarm is set. A differential detected above that level results in an inverter trip and open contacts at the combiner box.



renewable energy

Remedy

- **Notification of ground fault(s) by monitoring system**
  - ❑ Eliminate 24 hour delay for maintenance responders and identifies fault types
  - ❑ Add additional local monitor, data acquisition and weather monitoring
- **Contact Combiner Boxes with automatic disconnect**
  - ❑ Replace or upgrade combiner boxes to include automatic feeder and string DC disconnects from a remote and/or local signal
  - ❑ New contact combiner boxes capable of future arc fault detection
- **Improved DC Wire Management**
  - ❑ Physically remove or reduce stress points
  - ❑ Increased inspections, test, thermal imaging, megger test
- **Fire/Safety Brochure**

Duke Energy

renewable energy

Fire Safety Brochure

FIRE DEPARTMENT EMERGENCY OPERATIONS

- The PV array will always generate electricity during daylight even when cloudy, raining, snowing, etc and there is no turning off the generation of electricity. During daylight PV panels will be energized and and cannot be dedenergized!
- Consider all PV equipment and wires energized and do not touch or cut into or through PV modules, conduit and equipment!
- Do not open combiner box (square box usually only on large commercial units) – all energized wires from the solar panels are fed into the combiner box. Then they are combined into two large high current wires. Opening this box is dangerous. Boxes are normally locked.
- Wear SCBA and full protective clothing.
- Be aware that biting and stinging insects could inhabit the module frame and junction boxes.

If solar panels or batteries are on fire:

- Locate battery storage area (if applicable).
- Shelter-in-place populations-at-risk downwind.
- Extinguish lead-acid battery fires with CO_2, foam or dry chemical fire extinguishers.
- Use Class C extinguishing agents - CO_2 or dry chemical if a PV system shorts and starts a fire.
- Should the array become engulfed in a fire, use water in a fog pattern on the PV array, maintaining a minimum of 33 feet distance away from the energized source.
- Never assume that equipment is de-energized.

IN EMERGENCIES,
CALL DUKE ENERGY FOR ASSISTANCE:

- Indiana: 800-343-3525
- North Carolina: 800-769-3766
- South Carolina: 800-769-3766
- Ohio / Kentucky: 800-544-6900

Duke Energy®

526 South Church Street
Charlotte, NC 28202

www.duke-energy.com/safety

110874 | 10/11

FIRE SAFETY GUIDELINES FOR ROOFTOP- AND GROUND-MOUNTED SOLAR PHOTOVOLTAIC (PV) SYSTEMS

Duke Energy®

This brochure is designed for fire personnel responding to a fire where rooftop- and ground-mounted solar photovoltaic (PV) systems have been installed.

Findings

- Unique PV solar characteristics
  - Large amount of Direct Current (“DC”) equipment and wiring
  - Many designers, installers and inspectors have limited DC knowledge and are learning with each installation
  - Electric generation above panel rating is typical
  - PV grounding needs more attention

Findings

- **Ground Fault Measurement**
  - Ground faults measured at the inverter can be less than the actual ground fault measured at the source.
  - Current can be separated between ground and feeder.
  - More ground faults than expected go undetected.
  - More ground faults occur during the spring and fall.

Recommendations

- Independent third party inspections
  - Recommended when Owner and/or Buyer does not have in-house PV solar specialist
  - Inspectors should review both design and installation
- Third Party continuous monitoring
  - Recommend for 100 kw or larger sites
- Report Incidents
  - Solar industry can benefit by learning from others
  - It takes a long time for codes to be updated